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# THE VALUE OF CERTAIN CRITERIA FOR THE DETERMINATION OF THE ORIGIN OF FOLIATED CRYSTALLINE ROCKS. II

J. D. TRUEMAN  
University of Wisconsin

## PART II

### CHEMICAL COMPOSITION AS A CRITERION FOR THE DETERMINATION OF THE IGNEOUS OR SEDIMENTARY ORIGIN OF FOLIATED ROCKS

#### VIEWS OF OTHER WRITERS

It has long been well known that igneous rocks exhibit certain characteristic regularities in the amounts and proportions of their oxides, such as are not observed among sedimentary rocks. The composition of the latter is in part dependent upon the relative solubilities of minerals under weathering conditions, but also to a large extent upon the somewhat erratic redistribution of material during sedimentation. H. Rosenbusch<sup>1</sup> was the first to point out clearly the possibility of the application of chemical composition as a means of determining the original character of metamorphosed rocks. He considered that no important changes take place during dynamometamorphism because, first, many altered rocks possess a composition similar to that of certain normal igneous types and, second, on account of the preservation of clean-cut divisions between altered sedimentary strata of different composition. As a distinguishing feature between altered igneous and sedimentary rocks he pointed out that in the latter the molecular ratio of  $\text{Al}_2\text{O}_3$  to  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ , and  $\text{CaO}$  was greater than 1.

E. S. Bastin<sup>2</sup> has published the latest and most complete study regarding chemical composition as a criterion for the recognition of the original character of metamorphic rocks. From an examination of available analyses Bastin has determined certain distinguish-

<sup>1</sup> *Tschermak's Min. petrog. Mitt.*, XII (1891), 49.

<sup>2</sup> *Jour. Geol.*, XVII (1909), 445.

ing differences between the compositions of igneous and sedimentary rocks. His reasons for considering that the composition of a rock remains substantially unchanged during the development of foliation and that, consequently, it can be used as a criterion for the determination of the original character of a metamorphic rock are, briefly, based on the following: the application of criteria derived from normal igneous and sedimentary types to metamorphic examples whose origin has been established by other evidences and, second, instances in which the chemical compositions of both altered and unaltered rocks are known, a dike described by Teall<sup>1</sup> being used as an example. Bastin summarizes his conclusions as follows:

Dominance of MgO over CaO is strongly indicative of sedimentary origin.

Dominance of K<sub>2</sub>O over Na<sub>2</sub>O is of lesser critical value, but is nevertheless suggestive of sedimentary origin.

The double relationship of dominance of MgO over CaO and K<sub>2</sub>O over Na<sub>2</sub>O affords very strong evidence of sedimentary origin.

The presence of any considerable excess of Al<sub>2</sub>O<sub>3</sub> in the analysis over and above the 1:1 ratio necessary to satisfy the lime and alkalis is also suggestive of sedimentary origin.

High silica content may be indicative of sedimentary origin when supported by other criteria. This criterion must, however, be used with caution, since silication probably takes place in the dynamic metamorphism of certain igneous rocks.

When three or all of the above relationships hold good, the evidence of sedimentary origin may be regarded as practically conclusive.

It is, perhaps, advisable to mention here that in the case of many, possibly in the majority of, igneous rocks either the MgO is in excess over the CaO or the K<sub>2</sub>O over the Na<sub>2</sub>O, a fact which Bastin recognized. The tables of Washington show that in the majority of igneous rocks containing over 70 per cent of silica the K<sub>2</sub>O is in excess over Na<sub>2</sub>O. Indeed it is not till the silica has dropped to less than 60 per cent that the dominance of Na<sub>2</sub>O becomes marked. Accordingly, while the double relationship is, apparently, significant, the single ratios have but little value.

For some years C. K. Leith and W. J. Mead, of the University of Wisconsin, have had under consideration the possibility of marked changes in composition during the development of foliation in rocks.

<sup>1</sup> J. J. H. Teall, *Q.J. Geol. Soc.*, London, XLI (1885), 133.

It has been their opinion that the development of platy minerals as chlorite, sericite, etc., was the significant feature in the chemical changes, and that there is a tendency for constituents unnecessary for the formation of such minerals to be removed during the process of alteration. The evidence for this change in composition consists largely of the following: (a) field observations showing the development of schists from rocks which, on mineralogical grounds, would seem to have necessarily undergone a change in chemical composition during the formation of the metamorphic rock; (b) pairs of analyses representing the compositions of various unaltered rocks and the foliated derivatives from them. It is to be regretted that there are few such pairs of analyses available. Such as are known, however, indicate that rocks may undergo radical changes in chemical composition during the development of foliation.

An intimate knowledge of the field and chemical data outlined above as supporting the idea of change in composition during metamorphism would be necessary before their value as proof could be adequately discussed. The writer will, accordingly, confine his attention largely to the following occurrence with which he is personally familiar, but which has also been considered for some time by Dr. Leith and others to exemplify the chemical changes which a rock undergoes during the development of foliation.

#### THE ALTERATION OF QUARTZITE TO SERICITE SCHIST AT WATERLOO, WIS.

At Waterloo, Wis., there are exposures of a pre-Cambrian quartzite in which bands or lenses of a sericite schist have been developed. The quartzite has been described by many writers but J. H. Warner, while a student at the University of Wisconsin, was the first to study it with the idea of chemical change in mind. As a result of his investigations he concluded that the schist could have developed from the quartzite by a loss of silica without any introduction of material from the outside. He did not, however, dismiss the possibility of the schist representing argillaceous layers, or of part of the chemical differences between the schist and quartzite being due to the introduction of material from pegmatite dikes, such as are known to occur in one group of quartzite outcrops. The

work of the writer has been largely confined to the examination of the zircon and ilmenite contents of the rocks in order to obtain further evidence of chemical change during metamorphism. At the same time the rocks were studied in the field and under the microscope.

*Data.*—The quartzite exposures are not continuous but afford excellent opportunities for study, especially as a quarry has been opened up in one of the largest outcrops. Though the rock has been strongly folded, its bedding can generally be determined by means of conglomeratic layers. The schistose bands, which are seldom over two inches in thickness, may in some cases lie parallel to the bedding but in others they distinctly cut it.

The quartzite is of a dense crystalline type. It is predominately grayish in color, though vitreous and reddish phases also occur. Frequently specks of black iron oxide (ilmenite) and light-colored mica can be detected in the hand specimen. Under the microscope the fragmental texture can be recognized though the rock has suffered considerable granulation and recrystallization. Between the quartz grains are varying amounts of sericite and ilmenite with a few crystals of zircon. The sericite occurs in small flakes which are generally parallel to the borders of the quartz particles while the ilmenite is present in irregular grains. Sometimes the zircons are surrounded by quartz which seems, in some cases at least, to be of secondary origin.

The sericite schist is a uniform, fine-grained micaceous rock, generally of a pale greenish-yellow color. Under the microscope it is seen to consist of the same minerals as the quartzite except that the quartz has largely been replaced by sericite. In some places, associated with the sericite bands, are small stringers of quartz. The sericite flakes occasionally bend around portions of the quartz veins, suggesting that at least part of the quartz was present during the formation of the sericite.

The writer has separated the zircon and ilmenite grains from several specimens of the quartzite and schist by panning and the use of heavy solutions. It was found that the amount of ilmenite and zircon was in each case unusually large and that, apparently, both minerals were more abundant in the schist than in the quartz-

ite. Microscopic examination did not reveal any differences between the minerals present in the schist and those in the quartzite. The zircons from the two rocks are illustrated in Figs. 10 and 11. Many of the grains appear to be more or less rounded but in quite a number of instances the original outlines of the crystals can be seen. Some of the zircons may have remained in the quartz grains during sedimentation but the coating of iron oxide

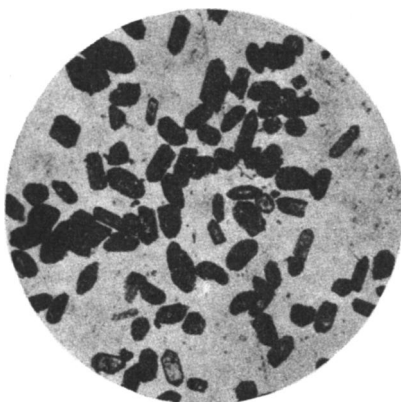


FIG. 10.—Zircons from quartzite, Waterloo, Wis.  $\times 32$ .

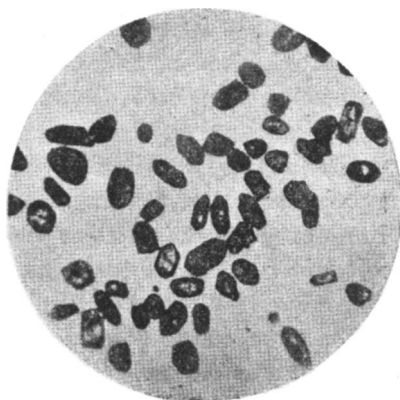


FIG. 11.—Zircons from sericite schist, Waterloo, Wis.  $\times 32$ .

around practically every crystal seems to indicate that this was not generally the case.

The following analyses of material obtained by combining samples from three localities in the area were made for the writer by O. L. Barneby, of the University of Wisconsin.

	Quartzite	Sericite Schist
TiO <sub>2</sub> .....	1.00	2.13
ZrO <sub>2</sub> .....	.25	.45

These may be compared with the analyses of J. H. Warner. It must be remembered, however, that these pairs of analyses were made from different samples and one set cannot be regarded as the complement of the other.

## ANALYSES BY J. H. WARNER

	Quartzite	Sericite Schist
SiO <sub>2</sub> . . . . .	86.60	58.61
Al <sub>2</sub> O <sub>3</sub> & TiO <sub>2</sub> . . . . .	7.69	22.73
FeO, Fe <sub>2</sub> O <sub>3</sub> . . . . .	3.72	9.73
K <sub>2</sub> O . . . . .	1.102	2.85
Na <sub>2</sub> O . . . . .	.508	1.18
Loss by ignition . . . . .	.90	2.92

A test by panning made on material from a pegmatite dike in the quartzite some miles from the locality in which the schistose bands were developed did not reveal the presence of either zircon or ilmenite.

*Conclusions.*—The evidence showing that the bands of sericite schist are not altered argillaceous bands which may have undergone little change in composition during metamorphism may be summarized as follows:

a) Field evidence shows that the schistose bands are sometimes developed directly across the bedding. In many cases where they might be considered to have developed parallel to the bedding the schistose zones are lens shaped and cannot be traced to any argillaceous layer in the quartzite.

b) Zircon is usually formed only in igneous melts. During sedimentation the zircon grains become concentrated in the arenaceous beds and they are almost absent from argillaceous deposits. In the sericite schist, which has roughly the composition of an argillaceous sediment, zircon is present in amounts large even for arenaceous beds. It is decidedly in greater abundance in the sericite schist than in the quartzite.

c) Ilmenite is generally considered to form only under conditions of high temperature and it is usually associated with igneous rocks. There is no evidence that it has been formed secondarily in either the quartzite or the sericite schist. It is a heavy mineral and like zircon would be concentrated in the arenaceous beds during sedimentation, yet it is decidedly more abundant in the schist than in the quartzite.

The following evidences seem to indicate that the difference in

composition between the schist and the quartzite was not caused by the introduction of material from igneous intrusives.

a) There are no igneous intrusives known to cut the quartzite except pegmatite dikes several miles from the outcrops from which the samples of quartzite and schist were taken. These dikes do not appear to contain either zircon or ilmenite.

b) Neither zircon nor ilmenite are minerals which are known to develop in small grains throughout a contact rock. Neither mineral has a freshly crystallized appearance either in the quartzite or schist.

c) There are no minerals in the schist which do not occur to some extent in the quartzite.

The following points seem to show that the sericite schist has generally been developed from the normal quartzite by dynamo-metamorphism and that during the alteration there has been a large loss in material, probably mostly silica:

a) Both  $\text{TiO}_2$  and  $\text{ZrO}_2$  are distinctly more abundant in the schist than in the quartzite. The ratio of the increase in percentage is in each case approximately the same.

b) Warner's analyses show that the percentage of all other constituents except silica is greater in the schist than in the quartzite and that the ratio of the increase in amount is in each oxide, except silica, approximately the same.

c) Presence of quartz stringers associated with some of the bands seems to indicate that quartz was eliminated during the formation of the schist.

On an assumption of such a change in composition, as outlined, it is to be supposed that all gradations must exist between the normal quartzite and the most highly developed sericite schist. This affords a satisfactory explanation why Warner's figures seem to indicate a concentration of as high as 2.6 or even 2.9 while the more recent analyses of  $\text{TiO}_2$  and  $\text{ZrO}_2$  only indicate a concentration of about 2. It is to be hoped that a complete analysis of the two rocks will some day be available in order, that by comparison with the  $\text{ZrO}_2$  and  $\text{TiO}_2$  it may be possible to obtain more definite proof of the relative stabilities of the oxides during the alteration.



OTHER SERICITE SCHISTS WHICH HAVE PROBABLY ORIGINATED  
FROM QUARTZITE

It is interesting, at this point, to recall the case of the sericite schist described by Thürach<sup>1</sup> as containing abundant zircons. This rock is associated with the Taunus quartzite which also contains a large content of zircon. While the shale-like composition of the sericite schist may in large part be due to the original argillaceous character of the rock, it is possible that, to some degree at least, it results from a more silicious rock by a loss of quartz and a concentration of impurities.

More striking is a case described by Derby<sup>2</sup> in which there seems good reason for supposing that the sericite schist has a similar origin to that at Waterloo. Derby states that in appearance this rock is "*a purely micaceous rock with no evidence, even in the heavy residue, of more than the merest trace of free quartz and hematite. . . .*" The rock probably contains over 80 per cent of an iron bearing sericite with, perhaps, 7 per cent, more or less, of chlorite and a small percentage of quartz and earthy iron oxide. Washings reveal a small amount of secondary tourmaline, of which the grains appear to be secondarily enlarged, and *worn zircons of a size and abundance that seem extraordinary in a rock of such fine grain and of so purely argillaceous character.*" The analysis of this sericite schist is given below in column 1.

	1	2
SiO <sub>2</sub> . . . . .	47.83	58.85
Al <sub>2</sub> O <sub>3</sub> . . . . .	26.75	26.22
Fe <sub>2</sub> O <sub>3</sub> . . . . .	8.51	3.01
FeO . . . . .	.....	.17
MgO . . . . .	2.43	.63
K <sub>2</sub> O . . . . .	10.42	8.44
Na <sub>2</sub> O . . . . .	.....	1.18
H <sub>2</sub> O . . . . .	.....	2.31
Ignition . . . . .	5.33	.....

1. Schist found loose in the diamond mine of São João da Chapada, but presumed to come from a schistose layer in a conglomeratic quartzite.

<sup>1</sup> Würzburg, *Phys.-Medic. Gesellsch.*, XVIII (1884).

<sup>2</sup> O. A. Derby, *Am. Jour. Sci.*, 4th Ser., X (1900), 207-16.

2. Mesnard sericite schist. Column 2 represents the composition of the sericite schist which occurs at the base of the Mesnard quartzite in the Marquette district of the Lake Superior region. This has been recently described<sup>1</sup> as having been probably formed from quartzite by loss of silica, the other oxides being present in the same proportion in the two rocks. Tests made on these rocks by the writer showed that zircon, while present in each case, was not sufficiently abundant to enable conclusions to be drawn regarding chemical change during metamorphism.

#### THE CHARACTER OF THE CHEMICAL CHANGES DURING THE DEVELOPMENT OF FOLIATION

With regard to the nature and importance of the chemical changes which take place during the development of foliation it is only possible, at the present time, to indicate a few suggestions. Needless to say, the final composition is dependent on many factors, the principal of which are: the original mineralogical and chemical composition of the rock, the intensity and duration of dynamic action, the depth of burial and the proximity to igneous intrusions.

In the absence of igneous activity, the process of alteration seems to favor the production of a composition determined largely by that of certain platy minerals which are relatively stable under the conditions of differential pressure. The character of the platy minerals which form seems to depend to a marked degree upon the original composition of the rock, e.g., a talc schist appears to be the usual metamorphic product of a limestone as sericite schist is of a quartzite. In the case of the quartzite, by the way, the writer's observations suggest that with very intense metamorphism the sericite and iron oxide present in the less altered rock may combine, leading to the formation of a biotite schist much darker in color than the original.

To illustrate the variation in the amount and direction of chemical change for any oxide in the case of rocks of different composition, the  $\text{SiO}_2$  content may be considered. The platy minerals mentioned in the last paragraph, being all silicates, have a somewhat limited range in the  $\text{SiO}_2$  percentage. It is, accordingly, to

<sup>1</sup> *U.S.G.S. Mono., LII* (1911), 257.

be expected that the  $\text{SiO}_2$  content would tend to become lower or higher than that in the original rock, according as to whether the original  $\text{SiO}_2$  lay above or below that range. This is illustrated in the following figure.

On the ordinate are plotted the percentages of silica, the composition of the original rocks being represented by circular signs, the white symbols representing quartzite, the shaded shale, and the black limestone. The crosses immediately above or below each

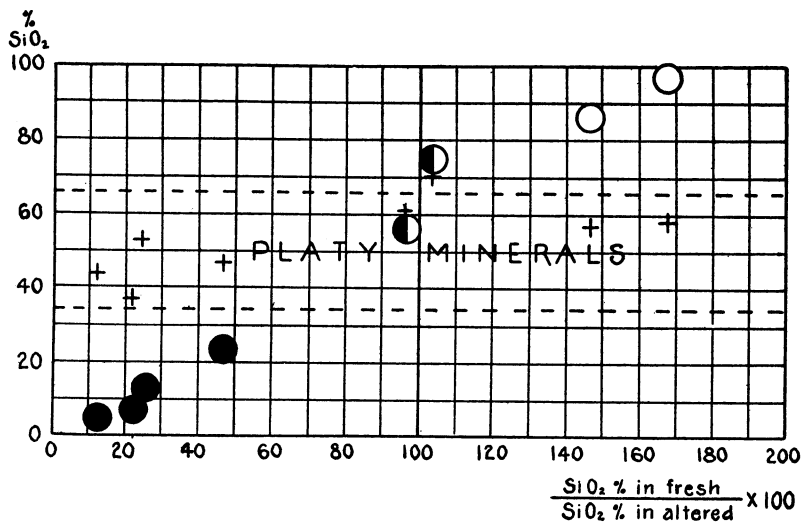


FIG. 12

of these signs represent the percentage of  $\text{SiO}_2$  in the altered rock. Along the abscissa are plotted the ratios of the  $\text{SiO}_2$  percentages of the fresh rocks to those of the altered rocks. For convenience the ratio is multiplied by 100 in the figures. Rocks appearing to the right of the 100 division show a decrease in silica percentage during alteration according to the distance which the symbol is from the 100 division, and similarly those to the left of the 100 division have gained in silica according to the distance of the symbol from the 100 division. The dotted horizontal lines include the approximate range for silica in the platy minerals. It is not to be supposed that the theoretical percentage is reached in any case though it is probable that those below the requirements have

generally gained and those above lost in  $\text{SiO}_2$  percentage. As the preceding diagram is not intended to represent a tabulation of facts so much as to indicate one of the probable courses of chemical change, it has not been considered necessary to state the references for the rock analyses used, though the best available ones were employed.

In regard to other oxides than  $\text{SiO}_2$ , it seems that the platy minerals are, in general, characterized by low  $\text{CaO}$  and  $\text{Na}_2\text{O}$  content and they are generally high in  $\text{Al}_2\text{O}_3$  and  $\text{H}_2\text{O}$  as compared with an average composition of igneous rocks. When these oxides are higher than the amount required to form platy minerals one might suppose from analogy with  $\text{SiO}_2$  that they would tend to become partially eliminated during the development of foliation provided that they are in a soluble form. Available analyses indicate that such is the case. Further investigations are, however, needed before exact figures can be determined.

Near igneous intrusions the process of chemical change is probably generally different from that which takes place during dynamo-metamorphism, and the introduction of material from the magma may lead to a composition different from that which would be expected in the latter case. Possibly the resulting composition would be nearer that of an igneous rock in character.

#### CAN CHEMICAL COMPOSITION BE USED AS A CRITERION FOR THE DETERMINATION OF THE ORIGIN OF FOLIATED ROCKS?

The answer to this question can only be satisfactorily determined by careful chemical studies accompanied by close field observations. It will depend mainly on two factors: first, the character of the chemical changes as compared with the characteristic differences in chemical composition between igneous and sedimentary rocks, and, second, on the extent of the chemical change in large bodies of rock.

Regarding the first, it is to be noted that platy minerals are, as a rule, rather low in  $\text{CaO}$  and  $\text{Na}_2\text{O}$  and somewhat high in  $\text{Al}_2\text{O}_3$ , as compared with average igneous rocks. An increase of such minerals would seem to lead to a composition similar to the sedimentary type described by Bastin. An examination of analyses,

indeed, shows that practically all mica schists have, according to the criteria mentioned, the composition of sedimentary rocks. Probably the majority of such schists do represent altered sediments although some have been described<sup>1</sup> as originating from igneous rocks. It seems likely that if biotite in many igneous rocks were increased to 25 per cent, as was tested in the case of the Butte granite, with a corresponding decrease of other constituents, a sedimentary composition would be reached. Chlorite, which frequently forms the major part of some schists derived from igneous rocks also possesses a composition belonging to the sedimentary type rather than the igneous.

Less, even, is known of the extent of the chemical changes than their character, probably because it has not been generally held that rocks suffer significant chemical changes during the development of foliation. The sericite schist associated with the Mesnard quartzite is an important rock formation, and the chemical changes involved in its formation from a quartzite would be enormous. The writer is of the opinion that while chemical change during the development of sericite schist from quartzite is very striking, less marked changes probably take place more readily in igneous or argillaceous rocks since the latter types more readily undergo differential movement, a process which seems essential for the production of schistosity.

Proof of important changes in chemical composition during the development of foliation in certain rocks will not necessarily destroy the usefulness of chemical data as a criterion, though its limitations will become better recognized. The origin of igneous rocks which have not been greatly altered may, for example, possibly be recognized with some certainty from the chemical composition, since the process of alteration seems to tend toward that of the sedimentary type.

#### GENERAL SUMMARY

In the introduction to this article the writer has attempted to give a brief summary of the criteria which have been suggested for determining the origin of foliated crystalline rocks. These rocks

<sup>1</sup> E.g., A. Keith, *U.S.G.S. Folio 70*, 1901, p. 2.

may be divided into two classes: (1) those which received their foliation during consolidation from an igneous melt, (2) those in which the foliation is a secondary structure. Many geologists do not acknowledge the importance of the first group though gneisses have been described as such by many well-known writers. A review of the criteria for distinguishing these primary gneisses from metamorphic foliated rocks shows that the most significant distinctions are based on field observations. It has been frequently considered important to determine whether certain foliated crystalline rocks were originally sedimentary or igneous in character. Numerous field, microscopic, and chemical methods have been suggested for distinguishing these classes but it can hardly be claimed that the results of their application have been entirely satisfactory. The various methods proposed have been reviewed by the writer.

Three of the methods suggested for the identification of foliated crystalline rocks have been treated in the preceding article in some detail. They are: (1) the criterion of texture as applied to primary gneisses, (2) uses of zircon as a criterion (chiefly for distinguishing the original igneous or sedimentary character of rocks), (3) use of chemical composition as a means of determining igneous or sedimentary origin.

It seems plausible that primary gneisses, which are in reality only igneous rocks with a banded structure, could be distinguished from metamorphic rocks by means of texture. Grubenmann has made a careful study of the texture of metamorphic rocks and has proposed a rather complete system of nomenclature for the different types. This is being adopted by many German geologists but its introduction into English is rendered difficult by the conflicting meanings of "texture" and "structure" in the two languages. Grubenmann calls the texture characteristic of "crystalline schists" "crystalloblastic" and considers that it is distinguished from igneous texture largely by features caused by the simultaneous crystallization of the different minerals instead of the more or less successive crystallization common to igneous rocks. Milch, according to a recent article, seems of the opinion that texture will be found to be the distinguishing feature of

primary gneisses. Views regarding the mode of formation and the shape of certain minerals of primary gneisses have been discussed by the writer in order that the manner of the crystallization of these rocks may be understood. It has frequently been stated that the foliation in such rocks is due to the rotation of minerals in a still fluid magma. While this, no doubt, occurs in some instances the writer has endeavored to show largely by measurements of biotite grains that elongation of mineral constituents by crystallization under differential pressure must also be a very important factor in producing foliation. It is concluded that the typical texture of primary gneisses is more or less intermediate between the igneous and the metamorphic types but that owing to the conditions of formation of these rocks a crystalloblastic or even cataclastic texture may be superimposed on the original. Texture as a means of identifying primary gneisses seems, accordingly, of only limited application.

The suggestion that zircon be used as a criterion for the identification of igneous or sedimentary origin was made by Derby in 1891, but the method has not been adopted by many geologists. Zircons are widely distributed in igneous rocks and during sedimentation become rounded in form and concentrated in the arenaceous deposits. It is proposed that their presence and their character may serve as a means for determining the original character of foliated rocks. Essential to the application of zircon as a criterion is the question of its stability under metamorphic conditions. Derby was of the opinion that zircon could not form in a rock secondarily. The writer has shown by an example of secondary enlargement of zircon grains that this is not impossible. Other cases, however, appear to prove that zircon is sufficiently stable to be used as a criterion. The conclusions which seem justified regarding the use of zircon in this connection are briefly as follows: abundant, minute zircons in a rock indicates that the original rock was either igneous or an arenaceous sediment; when the grains are uniform in character, well crystallized, and fresh in appearance an igneous rock seems likely; when they are well rounded and lacking in luster the original rock was probably sedimentary; absence of zircon grains is confirmatory of sedi-

mentary origin but is only suggestive when other evidences are lacking; absence of zircon grains in quartzose layers indicates that such material is probably not of sedimentary origin but was deposited from solution; similarity in zircon grains may be used to establish the identity of altered rocks when the fresh types are available.

Chemical analysis has frequently been used as a means of determining the original igneous or sedimentary character of metamorphic rocks. Its use is based on the supposition that a rock, as a whole, undergoes no significant chemical change during the development of schistosity. C. K. Leith has recently suggested that such chemical changes may be important and are probably controlled by the composition of certain platy minerals. It has been his view that material unsuited for the formation of such minerals tends to become removed during the development of foliation. The proof of such chemical changes is largely based on, first, field observations which seem to show that in certain rock alterations there must have been changes in chemical composition on account of the mineralogical composition of the altered and unaltered rocks, and, second, pairs of analyses of fresh and altered rocks in which the proportion between the oxides necessary for the formation of the platy minerals have remained constant while the other oxides have usually decreased in amount in the altered rock. The writer introduces new evidence by the consideration of the percentage of zircon in fresh and altered rocks. Zircon, as has been shown before, generally remains unaltered during the development of foliation. The case of the quartzite at Waterloo, Wis., is discussed in some detail and it is shown, both by means of mechanical separation and chemical analysis, that the zircon content of the schist is much greater than that of the quartzite. Reasons are given for believing that the schistose bands do not represent argillaceous layers in the quartzite. The evidence of the zircon is supported by that of ilmenite which is also more abundant in the schist than in the quartzite. A short review of the mineral composition of platy minerals indicates that an increase of such minerals in a rock would lead to a composition belonging to the sedimentary type according to the criteria of Bastin. This



would, perhaps, seem to show that chemical analysis cannot be used satisfactorily as a criterion for determining original igneous or sedimentary character. It is probable, however, that composition may still be employed in this connection, to some extent at least, after the magnitude and character of the chemical changes involved in the production of schistosity in different rocks become better determined.